Detection, Classification, and Estimation of Radioactive Contraband from Uncertain, Low-Count Measurements

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The detection of special nuclear material (SNM) smuggled into our nation is a critical issue for homeland security as well as for areas of nonproliferation, manufacturing, and processing and tracking of material. Today's high-speed, high-throughput computers enable physics-based statistical models that capture the essential signatures of radionuclides (RN) to be incorporated into a sequential scheme (a Bayesian sequential processor) capable of online, real-time operation. This approach is applicable to a large variety of model-based problems in many other critical areas of LLNL efforts.

This project is focused on the detection, classification, and estimation of SNM from highly uncertain, low-count RN measurements using a statistical approach based on Bayesian inference and physics-based signal processing. The effort encompasses theory, simulation, experiments, and application. It will enable the development of advanced signal/image processing techniques for the next generation of processors.

Project Goals

We expect to develop the techniques to provide fast, reliable radiation detection methods capable of making a more rapid decision about the presence of SNM with higher confidence along with the ability to quantify performance. Our goal is to reliably detect kilograms of shielded Pu with a 95% detection probability at a 5% false alarm rate in less than a minute.

Relevance to LLNL Mission

The detection of illicit SNM is a top priority of LLNL in furthering its national security mission. Radionuclide detection, classification, and identification are critical for tracking the transportation of radiological materials by terrorists, an important goal in national and international security.

FY2009 Accomplishments and Results

Our FY2009 accomplishments were:
1. performance evaluation of a Bayesian detection scheme using both simulated and controlled experimental data;
2. development of a solution to the classification problem using the physics-based Bayesian processors;
3. development of the signal-processing transport model based on point-to-point modeling by incorporating transport physics for gamma rays or photons and validating the results with full-physics simulations;
4. application of the signal-processing transport model to investigate solutions to the Compton inversion problem for source determination; and
5. development of a theoretical solution to the detection problem incorporating Compton scattering physics into the processor.

The basic structure of the processor implementation is shown in Fig. 1. After the photon information (energy/rate) is extracted from the photon by the measurement electronics, it is *discriminated* to determine if it is associated with the target RN. If so, the parametric information is enhanced by performing *parameter estimation* and is input to update the sequential decision function to *decide* (detection) whether or not the target RN is present.

Results of this photon-by-photon processor are shown in Fig. 2. A computer demonstration of the processor is available. These results are very promising and demonstrate the

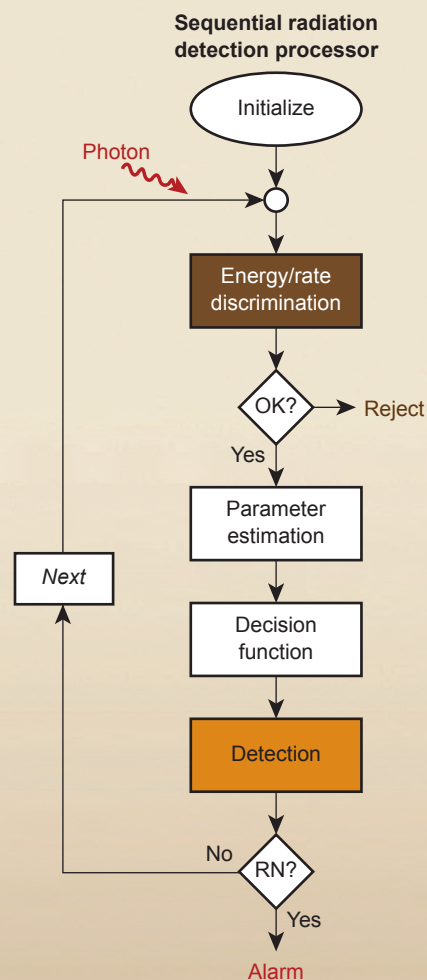**Sequential radiation detection processor**

Figure 1. The Bayesian design is shown (simply) as a photon-by-photon processor using a model-based (physics-based) processor to enhance the raw detector measurement while rejecting instrumentation noise and estimating the photoelectrons through energy/rate discrimination and parameter estimation. This information is input to a function used to detect which of the target RN are present.

potential capability of the Bayesian model-based approach to solving a variety of radiation detection problems.

Related References

1. Candy, J. V., E. Breitfeller, B. L. Guidry, D. Manatt, K. Sale, D. Chambers, M. A. Axelrod, and A. Meyer, "Radioactive Contraband Detection: A Bayesian Approach," *Proc. OCEANS09, IEEE OES Soc.*, 2009.
2. Candy, J. V., E. Breitfeller, B. L. Guidry, D. Manatt, K. Sale, D. H. Chambers, M. A. Axelrod, and A. M. Meyer, "Physics-Based Detection of Radioactive Contraband: A Sequential Bayesian Approach," *IEEE Trans. on Nuclear Science*, **56**, 6, 2, pp. 3694–3711, 2009.

FY2010 Proposed Work

In the remaining part of this project we plan to 1) demonstrate/evaluate the performance of the processor including Compton processing on controlled experimental data; 2) develop a solution based on the sodium-iodide detector measurements gathered previously; 3) cast the estimation of the threat mass problem into our model-based scheme for threat detection; and 4) develop a demonstration of the Bayesian scheme incorporating the processing of down-scattered photons (Compton) on simulated and experimental data. We expect to develop a radiation detection system capable of processing photon arrivals incorporating photon information extracted in a timely and reliable manner even in low-count environments.
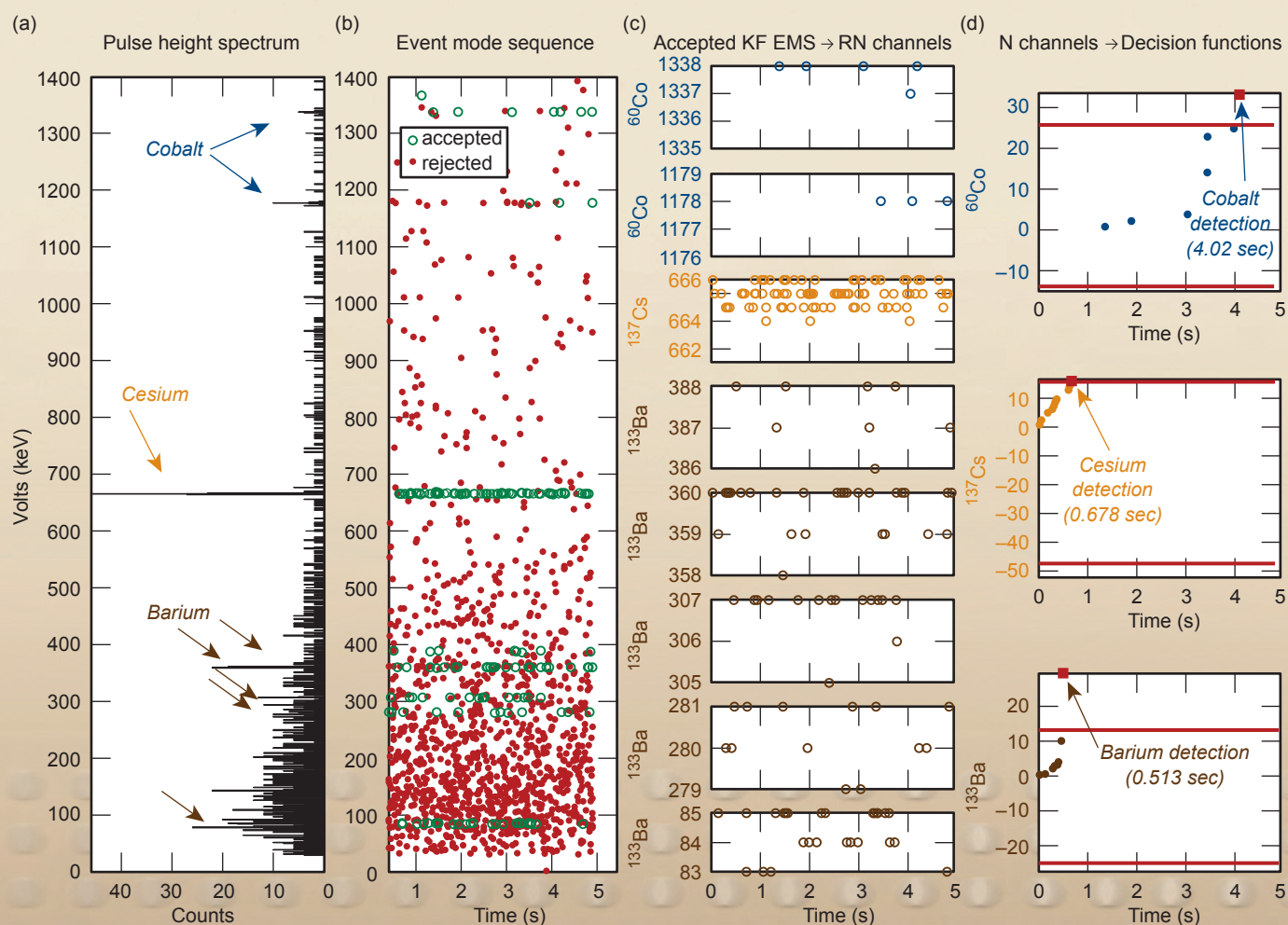

Figure 2. Sequential Bayesian detection and identification. (a) Pulse-height spectrum (after calibration); (b) photon arrivals (red) with discrimination (green circles); (c) enhanced energy estimates of targeted RN; (d) decision functions for ^{60}Co (detection time: 4.05 s), ^{137}Cs (detection time: 0.678 s) and ^{133}Ba (detection time: 0.513 s) with thresholds for RN detection/identification.